Contemporary Spine Surgery

VOLUME 22 ■ NUMBER 3 ■ MARCH 2021

Effectiveness of Bioskills Training in Spinal Surgery

James P. Foley, MD, and Wellington K. Hsu, MD

LEARNING OBJECTIVES: After participating in this CME activity, the spine surgeon should be better able to:

1. Describe the various types of bioskills training.
2. Distinguish the advantages and disadvantages of each bioskills training method.

Key Words: Bioskills, Education, Training

Bioskills training modules are educational tools, which intend to take surgical training out of the high-risk operating environment and allow trainees to safely learn and practice the complex skills involved.[1] Human cadavers have been the gold standard, but since the advent of synthetic models and virtual simulation, there is an ever-expanding list of ways to accomplish these goals for trainees. Each of these methods has their own inherent advantages and disadvantages, thus can be combined to maximize the educational benefit.

The pressures of resident work-hour restrictions, budget limitations, and medicolegal consequences of surgical complications have led residency programs across subspecialties to search for cost-effective and evidence-based methods of training qualified surgeons.[2] Spine surgery requires complex skills that take repeated practice to adequately master to minimize the risks to patients. This training has traditionally been done in an apprenticeship model in the operating room (OR) environment on live patients. In a review of orthopedic malpractice cases from 2010 to 2016, spine surgery was the most common subspecialty in cases, at 25.9%, followed by knee (21.0%) and hip (13.6%) procedures.[3] In other words, spine surgery is a high-risk surgical subspecialty, and has become a flash point of the inherent tension between maximizing patient safety and providing residents with adequate opportunities to gain experience.

McCarthy et al surveyed academic spine surgeons using a Likert scale[1-10] to gauge their assessment of perceived readiness for spine surgery after residency. Neurosurgical residents were perceived on average to be more prepared (8.17) than orthopedic residents (3.14) for practicing spinal surgery. This relative lack of readiness correlated with average spine case volume, of which orthopedic residents take part in less than half (41–80 cases) of their neurosurgical colleagues (200 cases). The number of procedures needed to achieve competence in these surgical procedures illustrates the importance of orthopedic spine fellowships, which add 300 to 500 cases.[1]

It has been demonstrated that the performance of complex surgical skills requires a "learning curve" and repetitive deliberate practice to master. For example, Gonzalvo et al[4] concluded that spine fellows needed to perform at least 40 to 80 pedicle screw placements to achieve reproducible accuracy consistent with attending level skill. In addition, Lee et al[5] reported competency for minimally invasive transforaminal lumbar interbody fusion to be achieved after 44 procedures. Bergeson et al[6] demonstrated that novice resident surgeons placing thoracic pedicle screws in cadavers were able to improve accuracy significantly, to competent levels, by the fourth cadaver. These more "shallow" learning curves illustrate the opportunity for residents to practice spine procedures and techniques in a safe environment outside the OR to gain proficiency.[7]

Dr. Foley is a Research Fellow, and Dr. Hsu is Clifford C. Raisbeck Distinguished Professor of Orthopaedic Surgery, Northwestern University Feinberg School of Medicine, 675 North Saint Clair St, Chicago, IL 60611; E-mail: james.foley@northwestern.edu.

Dr. Foley and all faculty and staff in a position to control the content of this CME activity, and their spouses/life partners (if any), have disclosed that they have no financial relationships with, or financial interests in, any commercial organizations relevant to this CME activity. Dr. Hsu has disclosed that he is a consultant for Stryker, Asahi, Wright Medical, Medtronic, and Bioventus. Lippincott CME Institute has identified and resolved all conflicts of interest concerning this educational activity.

Lippincott Continuing Medical Education Institute, Inc., is accredited by the Accreditation Council for Continuing Medical Education to provide continuing medical education for physicians. Lippincott Continuing Medical Education Institute, Inc., designates this enduring material for a maximum of 1.5 *AMA PRA Category 1 Credits*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity. To earn CME credit, you must read the CME article and complete the quiz and evaluation assessment survey on the enclosed form, answering at least 70% of the quiz questions correctly. This activity expires on February 28, 2023.

Surgical simulation allows trainees to safely practice performing technically difficult skills such as using high-speed drills and placing pedicle screws in confined places, which are essential in spine practice.[8] Simulation methods can be assessed for specific procedures and by the methods themselves. This article reviews the evidence and cost-effectiveness for each of these methods independently and in combination.

CADAVERS

As the gold standard for nonclinical surgical training, cadavers are widely used and popular with trainees.[1,9] They provide an opportunity for residents to practice skills such as handling instruments, surgical approaches, instrumentation, and decompression on a high-fidelity model of a real patient. Residents perceive the skills practiced in cadaver laboratories to be transferable to the OR through increased confidence, speed, and efficiency.[10]

In an experimental neurosurgical curriculum with cadavers, synthetic models, and computerized/haptic simulators, Gasco et al[9] reported cadavers as imparting the highest reported benefit by residents (71.5%), compared with physical simulators (63.8%) and haptic/computerized simulators (59.1%). Notably, junior residents [postgraduate years [PGY] 1–3] reported substantially higher educational benefit from cadavers than senior residents (PGY 4–6), 91.7% and 47.6%, respectively.[9] In a survey of orthopedic residents, Losco et al[10] reported that 45.7% of residents perceived cadaver skills sessions to be "extremely beneficial" for understanding specific surgical techniques, and 44.4% reporting them to be "very beneficial" for becoming familiar with arthroscopic or other surgical instruments; 60% of orthopedic residents reported cadaver laboratories to be "very" or "extremely" beneficial for improving speed and confidence in the OR.[10]

The benefits of cadavers will also vary based on preservation methodology. Cadavers can be preserved in several ways, notably formaldehyde or "formalin" embalmed, Thiel-embalmed, and Crosado-embalmed. Formalin (37%–39% formaldehyde) is the most widely used and can preserve cadavers for up to 3 years, but it is also a carcinogen, has an abrasive odor, and makes tissues stiff. Thiel cadavers also preserve tissue for up to 3 years, but keep joints flexible and tissue pliable better than formalin. Crosado cadavers use a low concentration of formalin (2%) and preserve bone and cartilage well. Tomlinson et al[11] compared Thiel-embalmed, Crosado-embalmed, and formaldehyde-embalmed cadavers for pedicle screw placement and had spine surgeons rate them using a

This continuing education activity is intended for orthopaedic and neurologic surgeons and other physicians with an interest in spine surgery.

Wolters Kluwer

Contemporary Spine Surgery (ISSN 1527-4268) is published monthly by Wolters Kluwer Health, Inc., at 14700 Citicorp Drive, Bldg 3, Hagerstown, MD 21742. **Customer Service: Phone (800) 638-3030, Fax (301) 223-2400, or E-mail customerservice@lww.com.** Visit our website at LWW.com.

Publisher: John Ewers

Suscription rates: *Individual:* US $522; international $683. *Institutional:* US $1142, international $1402. In-training: US resident $169 with no CME, international $193. Single Copies $118. Registration Number: 895524239.

7-point scale for fidelity to a live human. Thiel-embalmed cadavers rated highest for soft tissue feel and appearance (6/7), Crosado-embalmed cadavers were rated highest for bony feel (6/7), and formaldehyde-embalmed cadavers were lowest for both categories. If the primary educational goal is soft tissue based, such as the surgical approach, then a Thiel-embalmed cadaver would be best. If the training involves instrumentation, such as pedicle screw placement, then a Crosado-embalmed cadaver may be ideal for haptic feedback.[11]

Instrumentation skills seem to benefit most from cadavers in resident education. In particular, the reproducible, accurate placement of pedicle screws is a skill with a lengthy learning curve that requires understanding of complex anatomy and responsiveness to tactile feedback in differentiating cortical bone from cancellous bone.[12,13] The accuracy of screw placement has a direct effect on patient outcomes and need for revision surgery.[13] Cadaver bone is able to offer the tactile feedback that synthetic bone has yet to effectively replicate.[14]

Disadvantages of cadavers include the variable regional availability, high cost (US $2000–$4000), and costs of storage and maintenance of laboratories. In addition, because cadavers are predominantly obtained from the elderly population for whom osteoporotic bone is common, this can make tactile differentiation of cortical bone from cancellous bone more challenging.[14] In summary, the logistical, financial, and ethical barriers that limit the reliable supply of cadavers means training programs will continue to search for complementary or substitute methods of efficacious and cost-effective training models.

SYNTHETIC BONE MODELS

Sawbones

High costs, inconsistent availability, and lack of standardization between cadaver specimens have driven the development of a synthetic replacement that accurately recreates the anatomy and biomechanical properties of human bone. Early models of composite bones, before the late 1990s, required manual craftmanship of fiberglass material to produce and poorly replicated biomechanical properties of bone. In the late 1990s, the manufacturing process began using short glass fiber reinforced (SGFR) epoxy, which was able to be directly injected into castings made from an adult male donor for a high-fidelity anatomical reproduction of cortical bone. This process not only significantly decreased the labor needed to produce large quantities of composite bones, but also matched the biomechanical properties of human bone with SGFR epoxy.[15]

The current fourth-generation Sawbones are composite bone models, which have a cortical shell made of an even more optimized SGFR epoxy and cancellous core made of solid rigid polyurethane foam. Molds for epoxy injection are created and standardized using aggregate CT data from cadaveric bones.[15] Most normal spinal Sawbones cost under US $200, and pathologic models are slightly more expensive in the US $300 to $400 range. They are a low-cost alternative to cadavers, are easily acquired, have no special storage or preparation requirements, no risk of disease transmission, and have no ethical considerations.[16]

Sonnadara et al[17] demonstrated that surgical skills courses using Sawbones can be highly effective at teaching and developing targeted basic surgical skills in orthopedic trainees. Orthopedic PGY 1s at the University of Toronto were divided into 2 groups: participation in an intensive 30-day surgical skills course (n = 6) or in normal residency training (n = 16, half on-service, half off-service). All participants were assessed for 9 core surgical skills using an objective assessment of technical skills (OSATS) procedure before and after the 30-day period. Skills tested include hand scrubbing, gowning and gloving, prepping and draping, Foley catheter insertion, instrument identification, screw insertion into Sawbones, cutting a predesignated wedge out of Sawbones, wound closure, and applying a plaster splint. Residents in the intensive skills laboratory group performed better than their peers on both OSATS and global rating scale scores at the end of the 30 days, and the control group demonstrated no difference in scores between on-service and off-service residents.[17]

Boody et al[18] studied Sawbones in the context of a lumbar laminectomy bioskills training session and demonstrated objective improvement in trainees' technical and procedural skills. Participants (fourth-year medical students, residents) were randomized to control (n = 9) or intervention (n = 11). After a pretest assessment, the control group had 40 minutes of self-directed learning about lumbar decompression, whereas the intervention group underwent a 40-minute bioskills training module. This module consisted of a senior resident presenting a 10-minute PowerPoint highlighting the steps of the procedure, proper use of surgical instruments, and review of the 3-dimensional (3D) degenerative and normal anatomy using Sawbones models, followed by 30 minutes of practice performing lumbar decompressions on Sawbones models with active feedback from the presenter. Pre- and posttest performance was self-reported by each participant [Physician Performance Diagnostic Inventory Scale (PPDIS)], and objective evaluation was obtained from a blinded fellowship-training attending orthopedic spine surgeon using OSATS and Objective Decompression Score metrics. The intervention group demonstrated a significant mean improvement in OSATS (P = .022) and PPDIS (P = .0001) scores. The authors concluded that Sawbones training modules can be an efficient and effective tool for teaching fundamental spine surgical skills outside the OR (Figure 1).[18]

Hands-on orthopedic training with Sawbones may be a cost-effective, readily available method for residents and fellows to visualize the bony anatomy and practice the technical skills needed in the OR.[19] However, the lack of surrounding soft tissue elements and inability to replicate tactile feedback of the cortical and cancellous bone interface, due to little or no differences in internal structure or cortical shell thicknesses, make it an imperfect model for comprehensive OR simulation.[14]

3D Printed Spines

A recent innovation, 3D-printed spines offer several advantages over traditional Sawbones models. Hao et al[14] developed the 3D-printed MedPhantom, with the intended use to offer

Fig. 1 *Spine bioskills training laboratory arrangement.*

similar tactile feel, mechanical characteristics, and visual appearance as human vertebral bone. To accomplish this, the authors focused on creating an accurate representation of an internal trabecular framework within a solid print created from 15% gypsum mixed with 100% clear resin and 10% castable mixed with 90% clear resin (Figure 2). Biomechanical testing demonstrated the most high-fidelity composite bone dimensions to human vertebrae to be 2-mm cortical wall thickness, 3-mm gap size, and 0.3-mm radius of internal cylinders (replicating trabeculae). Surgeons assessing this model rated the tactile feel of trocar insertion, commonly used in minimally invasive spine surgery, to be similar to human bone.[14]

Park et al[12] created 3D-printed spine models using a protocol provided and validated for spinal fixation research by Wu et al,[20] which used real patient CT scans, and assessed residents performing free-hand lumbar pedicle screw placement.

Fig. 2 *Section cut of 3D-printed vertebrae showing internal mesh trabecular structure while housed within a thick cortical wall. Model was printed with 100% clear resin off the Form 2 SLA printer. (Reprinted with permission from John Hao, PhD.)*

There were significantly fewer wall breeches, and less mean length of time to complete between the first and second spine models, which were instrumented. Notably, no critical violations (>2 mm) occurred in the second group.[12]

From a training program perspective, Schwartz et al[21] reported an initial required investment of $52,000 to $56,000, which covers the printer, printer base cabinet, installation, training, and printer software, plus a 1-year warranty. This cost can potentially be lowered given the availability of open-source software.[22] Several companies are able to convert patient CT/MRI data into a 3D-printing format to print individualized models. Stratasys (Figure 3) is one of the most costly on the market; their PolyJet stereolithography (SLA) resin prints can range from $6000 to $20,000 (not including ownership of the printer). On the lower range, Formlabs SLA resin prints cost as little as $3500 (which includes ownership of the printer and resin). Future improvements in 3D printing technology combined with market competition will likely continue to decrease cost and reduce the pricing gap.[23]

SIMULATION SYSTEMS

The 3 broad categories of simulation systems include virtual reality (VR), mixed reality, and augmented reality (AR).[24] VR, wherein the entire simulation is virtual, has already been used in a teaching role to allow trainees to practice surgical procedures in a risk-free environment.[25-27] Mixed reality is virtual, combined with a physical simulator component. AR, when a virtual component is superimposed onto physical reality (ie heads-up display), is the most tested and has been successfully used clinically along the entire spine,[24,28,29] and for procedures ranging from deformity,[30] vertebroplasty,[31] to biopsy.[24] AR has been used for training purposes primarily through 3D navigation to assist pedicle screw placement.[29]

VR, which demonstrates promise for safe and effective spine surgery training, has not been studied as much as other methods. VR simulation has already been demonstrated to be effective in preoperative warm-ups by reducing errors and time of procedure.[32] In regard to spine surgery, improving pedicle screw accuracy is an area where VR offers advantages, given the risks to neural and vascular structures of misplaced screws. It has been

Fig. 3 *In-office Fortus 250 3D printer. (Reprinted with permission from Adam Schwartz, MD.)*

reported that residents have a 15% misplacement rate for thoracic pedicle screws, and the overall rate of pedicle screw breeches is 5.1%.[29,33] It requires an understanding of complex 3D anatomy to properly align each screw trajectory. In one randomized study of residents' ability to learn accurate lumbar pedicle screw placement, Shi et al[34] compared a virtual surgical training simulator with a traditional teaching session, which included a didactic spine model (40 minutes) and a video demonstration (10 minutes). Residents assigned to the virtual simulator had 30 minutes to practice bilateral pedicle screw insertion from L1 to L5. Both groups then placed pedicle screws by free-hand technique into cadavers, and CT scans of the spines were graded and assessed by 3 experienced observers. The VR simulation group was found to have significantly fewer pedicle breeches and greater pedicle screw accuracy compared with the didactic control group.[34]

ImmersiveTouch (Figure 4) is one known simulator on the market. ImmersiveTouch has been more thoroughly validated through research and provides haptic feedback. Additionally, the device simulates percutaneous lumbar puncture, Jamshidi needle biopsy, thoracic and lumbar pedicle screw placement, percutaneous spinal fixation, and vertebroplasty. It uses real patient CT and MRI data to create 3D representations, which can be used for preoperative planning and procedural practice. Another simulator, the Surgical Rehearsal Platform (Figure 5) uses patient imaging to create an interactive 3D setting for preoperative planning and procedural rehearsal, and is able to simulate pedicle screw trajectory before surgery.[35]

ImmersiveTouch states that the launch of ImmersiveView provides the only suite of integrated VR real-time solutions for personalized surgical planning, patient engagement, and surgical training using patented haptic technology.

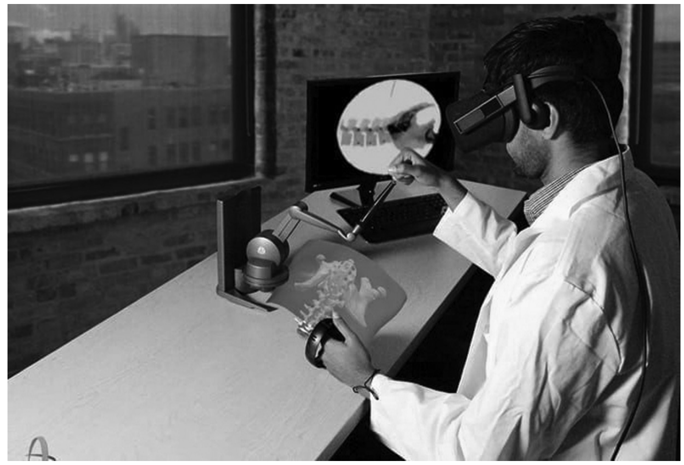

Fig. 4 *ImmersiveTouch simulator. (Reprinted with permission from ImmersiveTouch Inc.)*

VR simulation could be a valuable adjunct to resident education, but the lack of replication of manual skills and tactile feedback limit their usefulness to preoperative planning and understanding complex patient-specific 3D anatomy.[36] Haptic feedback and the ability to accurately manipulate tissue will be necessary components of a successful realistic VR training system, and its teaching potential can be strengthened through combination with physical simulation. Unfortunately, the significant financial investment to acquire these systems is another barrier to their widespread adoption by residency programs. Currently, virtual simulation has promising potential for applications in spine surgery training, but few prospective and randomized controls trials are available in the literature.

BIOSKILLS TRAINING COMBINATIONS

Each of these training methods has its inherent advantages and disadvantages. Cadavers most accurately represent human

Fig. 5 *Surgical Rehearsal Platform. (Reprinted with permission from Surgical Theater LLC.)*

anatomy and tissue, but come at a high cost, are not reusable, often have osteoporotic bone, rarely have spinal pathology, require additional staff and laboratory space, and have ethical concerns regarding their procurement and use. Synthetic models are portable, more reusable, and can simulate pathology, but they represent bone and soft tissue poorly. VR is reusable and can simulate pathology, but has a significantly high cost, less realistic haptic response, and requires technical expertise to maintain, and software subscriptions.

Pedicle screw instrumentation has been extensively evaluated using many combinations of simulations.[9,29,37-41] 3D navigation used with cadavers and Sawbones is another way for residents to improve the accuracy of pedicle screw placement, as demonstrated by Hou et al[40,41] in both the cervical and thoracic spine. Sundar et al[37] showed that augmented simulation using 3D navigational assistance combined with cadavers and Sawbones was superior to didactics alone at decreasing the overall pedicle screw placement error rate in the cervical, thoracic, and lumbar spine. In addition, Gottschalk et al[42] performed a blinded randomized controlled study of residents and reported that training with 3D navigation significantly improved the ability of residents to properly drill simulated cervical lateral mass screws. Gibby et al[38] demonstrated that a head-mounted display AR system with superimposed CT and Sawbones improved the accuracy of percutaneously placed pedicle screws. 3D navigation, already being widely used clinically, has also been demonstrated to be useful for resident training when combined with cadavers and Sawbones. Sundar et al[37] compared didactics alone versus didactics combined with cadavers, Sawbones, and 3D navigation, and found a decreased overall screw placement error rate when residents are given opportunities to practice using navigation. Although exposure to navigation, robotics, and VR can be helpful during resident training, we, like others, have emphasized the need to use direct and open anatomic exposure/training before using technology on a regular basis. Overreliance on these techniques can lead to an inability of residents to manually identify the correct entry points for pedicle screws.[43]

Decompression techniques also can benefit from a combination approach. High-speed drills and burrs require practice to handle, and bioskills training is a practical way to allow residents to handle these tools in a safe environment. Boody et al[18] reported a concise lumbar laminectomy bioskills training course combining didactics with practice on cadavers and Sawbones as an effective way of teaching. Additionally, Harrop et al[44] developed a cervical spine simulator for posterior cervical decompression (C8 foraminotomy and C3–C6 laminectomy) combined with a 2-hour didactic session, which significantly improved both OSATS technical scores and didactic scores for all participants. In addition to the pretest assessments, the didactic session incorporated a session on basic principles of cervical anatomy (15 minutes), hands-on training with faculty (60 minutes), and an explanation of the simulator (10 minutes). The greatest improvement from pretest to posttest scores was 20% for 2 individuals. The authors emphasized the benefit of setting clearly defined educational goals and 7 specific educational sections based on prior pilot studies with residents.[44]

Surgical simulation using these modalities allows residents to practically apply theoretical knowledge gained through didactics. A combination of different simulation methods seems to be especially effective.[1,13,18,37,38,40-42] Residents at different levels of training also rank the educational benefit of these methods differently, with junior residents benefiting the most from practice on cadavers and synthetic models, and senior residents reporting more benefit from the virtual simulators.[9]

DISCUSSION

Bioskills training using the discussed modalities has been demonstrated to be a safe and effective way to increase resident confidence and performance in learning spine surgery techniques such as instrumentation and decompression. They are most effective when used in combination, and residents are given independent and deliberate spaced opportunities to practice. Feedback from attending surgeons is also an important component.[35] A survey of attending orthopedic spine surgeons reported that they would be more likely to advance the participation of residents who demonstrate skills appropriately in a bioskills module. Sixty-two percent of respondents wanted to increase the time residents spend on bioskills, and reported faculty time constraints and financing to be the biggest factors limiting this increase. Forty percent reported their bioskills budget to be between US $1000 and $10,000. Given that spine surgeons believe the most beneficial aspect of bioskills training for residents is gaining a familiarity with instruments, synthetic models like Sawbones can fulfill this objective at a lower cost than cadavers.[1]

Training opportunities should also be stratified based on resident experience. Junior residents receive the greatest benefit from more basic training handling instruments and learning complex 3D anatomy; thus, a combination of didactics and applied practice on cadavers and Sawbones would be the most efficient use of their time.[1] Spaced repetition is a critical aspect of independent learning, so open access to these training tools for residents should be included.[10,45,46] Senior residents should have access to tools that facilitate practice of more advanced procedures such as pedicle screw placement and decompressions. While 3D navigation combined with cadavers and synthetic models is effective in improving residents' accuracy of pedicle screw placement, free-hand technique should be taught first to ensure independence and accuracy before use of technology.[43]

Incorporating 3D-printed spines from patient imaging into training modules offers an opportunity for residents to get practice operating on specific pathologies, which is a limitation of cadavers. 3D-printed materials and techniques are making progress to increasing the fidelity of tactile feedback to human bone. Costs of these machines and materials will continue to decrease due to market competition, and may offer a reliable alternative to cadavers in the near future. This would enable residency programs to control their own production of simulation models and tailor the training experience to whichever procedure or pathology they choose.

REFERENCES

1. McCarthy MH, Boody BS, Swiatek PR, et al. The perceived efficacy and utility of spine bioskills curricula for resident and fellow education. *J Orthop*. 2020;20:87-91.
2. West JL, Fargen KM, Aschenbrenner CA, et al. Commentary: resident operative experience: training an expert neurosurgeon. *Neurosurgery*. 2019;84(5):E279.
3. Rynecki ND, Coban D, Gantz O, et al. Medical malpractice in orthopedic surgery: a westlaw-based demographic analysis. *Orthopedics*. 2018;41(5):e615-e620.
4. Gonzalvo A, Fitt G, Liew S, et al. The learning curve of pedicle screw placement: how many screws are enough? *Spine (Phila Pa 1976)*. 2009;34(21):E761-E765.
5. Lee KH, Yeo W, Soeharno H, et al. Learning curve of a complex surgical technique: minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). *J Spinal Disord Tech*. 2014;27(7):E234-E240.
6. Bergeson RK, Schwend RM, DeLucia T, et al. How accurately do novice surgeons place thoracic pedicle screws with the free hand technique? *Spine (Phila Pa 1976)*. 2008;33(15):E501-E507.
7. Sharif S, Afsar A. Learning curve and minimally invasive spine surgery. *World Neurosurg.* 2018;119:472-478.
8. Walker JB, Perkins E, Harkey HL. A novel simulation model for minimally invasive spine surgery. *Neurosurgery.* 2009;65(6 suppl):188.
9. Gasco J, Holbrook TJ, Patel A, et al. Neurosurgery simulation in residency training: feasibility, cost, and educational benefit. *Neurosurgery*. 2013;73(suppl 1):39-45.
10. Losco CD, Grant WD, Armson A, et al. Effective methods of teaching and learning in anatomy as a basic science: a BEME systematic review: BEME guide no. 44. *Med Teach*. 2017;39(3):234-243.
11. Tomlinson JE, Yiasemidou M, Watts AL, et al. Cadaveric spinal surgery simulation: a comparison of cadaver types. *Global Spine J*. 2016;6(4):357-361.
12. Park HJ, Wang C, Choi KH, et al. Use of a life-size three-dimensional-printed spine model for pedicle screw instrumentation training. *J Orthop Surg Res*. 2018;13(1):86.
13. Boody BS, Hashmi SZ, Rosenthal BD, et al. The effectiveness of bioskills training for simulated lumbar pedicle screw placement. *Global Spine J*. 2018;8(6):557-562.
14. Hao J, Nangunoori R, Wu Y, et al. Material characterization and selection for 3D-printed spine models. *3D Print Med.* 2018;4(1):8.
15. Elfar J, Menorca RM, Reed JD, et al. Composite bone models in orthopaedic surgery research and education. *J Am Acad Orthop Surg*. 2014;22(2):111-120.
16. Sawbones USA. Test Materials and Composite Bone. 2020.
17. Sonnadara RR, Garbedian S, Safir O, et al. Toronto orthopaedic boot camp III: examining the efficacy of student-regulated learning during an intensive, laboratory-based surgical skills course. *Surgery*. 2013;154(1):29-33.
18. Boody BS, Rosenthal BD, Jenkins TJ, et al. The effectiveness of bioskills training for simulated open lumbar laminectomy. *Global Spine J*. 2017;7(8):794-800.
19. Coelho GF, Defino HLA. The role of mixed reality simulation for surgical training in spine: phase 1 validation. *Spine (Phila Pa 1976)*. 2018;43(22):1609-1616.
20. Wu AM, Shao ZX, Wang JS, et al. The accuracy of a method for printing three-dimensional spinal models. *PLoS One.* 2015;10(4):e0124291.
21. Schwartz A, Money K, Spangehl M, et al. Office-based rapid prototyping in orthopedic surgery: a novel planning technique and review of the literature. *Am J Orthop (Belle Mead NJ)*. 2015;44(1):19-25.
22. Frame M, Huntley JS. Rapid prototyping in orthopaedic surgery: a user's guide. *ScientificWorldJournal*. 2012;2012:838575.
23. Jones DB, Sung R, Weinberg C, et al. Three-dimensional modeling may improve surgical education and clinical practice. *Surg Innov*. 2016; 23(2):189-195.
24. Yoo JS, Patel DS, Hrynewycz NM, et al. The utility of virtual reality and augmented reality in spine surgery. *Ann Transl Med*. 2019;7(suppl 5): S171.
25. Yiannakopoulou E, Nikiteas N, Perrea D, et al. Virtual reality simulators and training in laparoscopic surgery. *Int J Surg*. 2015;13: 60-64.
26. Larsen CR, Soerensen JL, Grantcharov TP, et al. Effect of virtual reality training on laparoscopic surgery: randomised controlled trial. *BMJ*. 2009;338:b1802.
27. Youngblood PL, Srivastava S, Curet M, et al. Comparison of training on two laparoscopic simulators and assessment of skills transfer to surgical performance. *J Am Coll Surg*. 2005;200(4):546-551.
28. Mascitelli JR, Schlachter L, Chartrain AG, et al. Navigation-linked heads-up display in intracranial surgery: early experience. *Oper Neurosurg (Hagerstown)*. 2018;15(2):184-193.
29. Elmi-Terander A, Nachabe R, Skulason H, et al. Feasibility and accuracy of thoracolumbar minimally invasive pedicle screw placement with augmented reality navigation technology. *Spine (Phila Pa 1976)*. 2018;43(14):1018-1023.
30. Kosterhon M, Gutenberg A, Kantelhardt SR, et al. Navigation and image injection for control of bone removal and osteotomy planes in spine surgery. *Oper Neurosurg (Hagerstown)*. 2017;13(2):297-304.
31. Abe Y, Sato S, Kato K, et al. A novel 3D guidance system using augmented reality for percutaneous vertebroplasty: technical note. *J Neurosurg Spine*. 2013;19(4):492-501.
32. Kahol K, Satava RM, Ferrara J, et al. Effect of short-term pretrial practice on surgical proficiency in simulated environments: a randomized trial of the "preoperative warm-up" effect. *J Am Coll Surg*. 2009;208(2):255-268.
33. Lonstein JE, Denis F, Perra JH, et al. Complications associated with pedicle screws. *J Bone Joint Surg Am.* 1999;81(11):1519-1528.
34. Shi J, Hou Y, Lin Y, et al. Role of visuohaptic surgical training simulator in resident education of orthopedic surgery. *World Neurosurg*. 2018;111:e98-e104.
35. Bohm PE, Arnold PM. Simulation and resident education in spinal neurosurgery. *Surg Neurol Int*. 2015;6:33.
36. Breese R, Piazza M, Quinsey C, et al. Tactile skill-based neurosurgical simulators are effective and inexpensive. *World Neurosurg*. 2020;137: 319-326.
37. Sundar SJ, Healy AT, Kshettry VR, et al. A pilot study of the utility of a laboratory-based spinal fixation training program for neurosurgical residents. *J Neurosurg Spine*. 2016;24(5):850-856.
38. Gibby JT, Swenson SA, Cvetko S, et al. Head-mounted display augmented reality to guide pedicle screw placement utilizing computed tomography. *Int J Comput Assist Radiol Surg*. 2019;14(3): 525-535.
39. Ma L, Zhao Z, Chen F, et al. Augmented reality surgical navigation with ultrasound-assisted registration for pedicle screw placement: a pilot study. *Int J Comput Assist Radiol Surg*. 2017;12(12):2205-2215.
40. Hou Y, Lin Y, Shi J, et al. Effectiveness of the thoracic pedicle screw placement using the virtual surgical training system: a cadaver study. *Operative Neurosurgery*. 2018;15(6):677-685.
41. Hou Y, Shi J, Lin Y, et al. Virtual surgery simulation versus traditional approaches in training of residents in cervical pedicle screw placement. *Arch Orthop Trauma Surg*. 2018;138(6):777-782.
42. Gottschalk MB, Yoon ST, Park DK, et al. Surgical training using three-dimensional simulation in placement of cervical lateral mass screws: a blinded randomized control trial. *Spine J*. 2015;15(1):168-175.
43. Kaliya-Perumal AK, Soh T, Tan M, et al. Spinal navigation during orthopedic residency training: a double-edged sword? *Clin Orthop Surg*. 2019;11(2):170-175.
44. Harrop J, Rezai AR, Hoh DJ, et al. Neurosurgical training with a novel cervical spine simulator: posterior foraminotomy and laminectomy. *Neurosurgery*. 2013;73(suppl 1):94-99.
45. McGaghie WC, Issenberg SB, Petrusa ER, et al. A critical review of simulation-based medical education research: 2003-2009. *Med Educ*. 2010;44(1):50-63.
46. Ericsson KA, Nandagopal K, Roring RW. Toward a science of exceptional achievement: attaining superior performance through deliberate practice. *Ann N Y Acad Sci*. 2009;1172:199-217.

CME Quiz

To earn CME credit, you must read the CME article and complete the quiz and evaluation assessment survey on the enclosed form, answering at least 70% of the quiz questions correctly. **Select the best answer and use a blue or black pen to completely fill in the corresponding box on the enclosed answer form.** Please indicate any name and address changes directly on the answer form. If your name and address do not appear on the answer form, please print that information in the blank space at the top left of the page. Make a photocopy of the completed answer form for your own files and mail the original answer form to Wolters Kluwer Health, Continuing Education Department, P.O. Box 1543, Hagerstown, MD 21741-9914 by **February 28, 2023.** Only two entries will be considered for credit. For more information, call (800) 638-3030.

Online quiz instructions: To take the quiz online, **log on to your account at www.cssnewsletter.com**, and click on the "CME" tab at the top of the page. Then click on "Access the CME activity for this newsletter," which will take you to the log-in page for **http://cme.lww.com**. Enter your ***username*** and ***password.*** Follow the instructions on the site. You may print your official certificate ***immediately***. Please note: Lippincott CME Institute, Inc., ***will not*** mail certificates to online participants. **Online quizzes expire on the due date.**

The American Association of Neurological Surgeons (AANS) manually tracks *AMA PRA Category 1 Credits*™ earned from neurosurgery activities not sponsored or joint-sponsored by the AANS. As a service to AANS members, Lippincott CME Institute will continue to provide the AANS a monthly listing of their participants and the CME credits they earned so that AANS members do not have to send their individual certificates to the AANS for tracking.

Credits related to activities on orthopaedics may be applied to American Board of Orthopaedic Surgery Maintenance of Certification. Please confirm credit for specific activity with the Board at www.abos.org.

1. Which one of the following types of embalmed cadaver is *most* suitable for bone instrumentation?
A. Crosado-embalmed
B. Thiel-embalmed
C. Formalin-embalmed
D. Ethanol-embalmed

2. Which one of the following bioskills training modalities has the *most* overall benefit, according to junior residents (PGY 1–3)?
A. Sawbones
B. Cadavers
C. Virtual simulators
D. Didactics

3. Which one of the following bioskills training modalities has the *most* overall benefit, according to senior residents (PGY 4–6)?
A. Sawbones
B. Cadavers
C. Virtual simulators
D. Didactics

4. Which one of the following is a possible disadvantage of training residents in pedicle screw instrumentation using AR exclusively?
A. Increased instrumentation time
B. Decreased pedicle screw accuracy
C. Inability to manually identify screw entry points
D. More critical medial pedicle wall breeches ($>$2 mm)

5. Synthetic bone models can be created from patient CT/MRI data.
A. True
B. False

6. Orthopedic spine fellows can expect to add, on average, how many spine cases during their fellowship training?
A. 100 to 300
B. 200 to 400
C. 300 to 500
D. 400 to 600

7. Which one of the following orthopedic subspecialties is associated with the *highest* risk for malpractice cases?
A. Joints
B. Hand
C. Foot and ankle
D. Spine

8. Compared with the didactic control group, residents who practiced lumbar pedicle screw insertion on a virtual simulator demonstrated greater performance on pedicle screw accuracy and number of pedicle wall breeches.
A. True
B. False

9. How many pedicle screws does a trainee need to place to achieve an acceptable level of reproducible accuracy?
A. 0 to 40
B. 40 to 80
C. 80 to 120
D. 120 to 160

10. The use of AR in resident bioskills training has been demonstrated repeatedly to improve which one of the following?
A. Procedure time
B. Pedicle screw accuracy
C. Breech identification
D. Orthopaedic In-Training Examination score